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THE EVALUATION OF THE NEOTRON AS A POWER AMPLIFYING DEVICE FOR --ETC(U)
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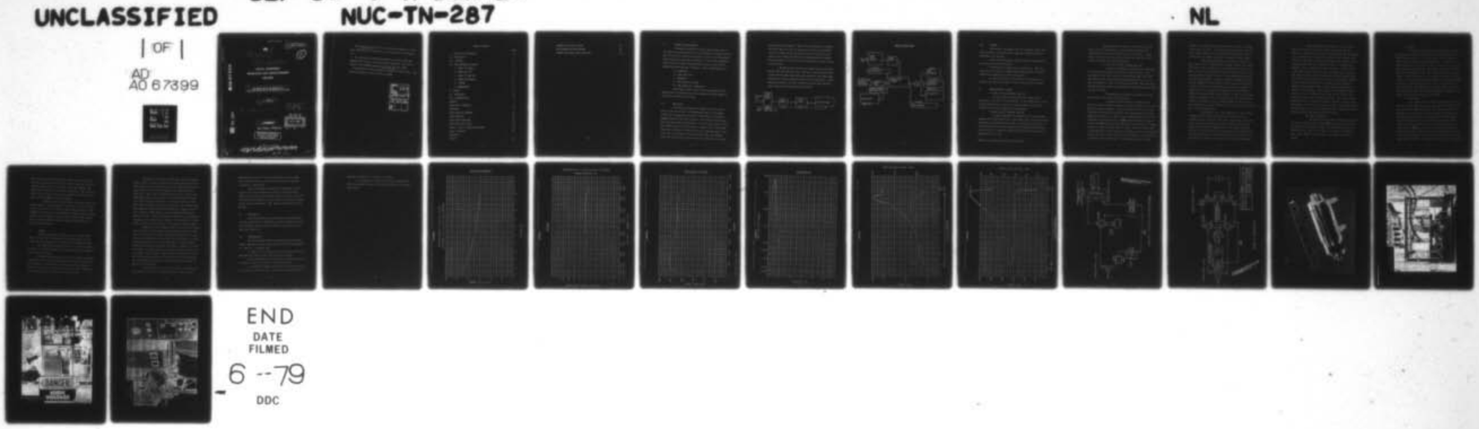

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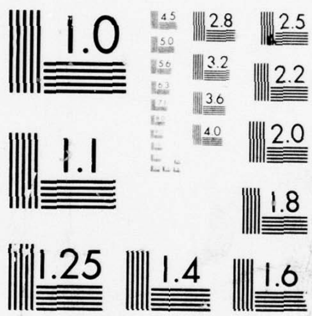

MICROCOPY RESOLUTION TEST CHART
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NAVAL UNDERSEA RESEARCH AND DEVELOPMENT CENTER

6 THE EVALUATION OF THE NEOTRON AS A POWER AMPLIFYING DEVICE FOR SONAR APPLICATIONS.

by

10 F. A./Dexter

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9 Technical note,

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San Diego, California

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This technical note describes the testing and evaluation of a new power amplifying device referred to as a field effect tube by Amperex Inc.

The evaluation was performed by members of the Sonic Sonar and Communications Division, Sensor Development Department. The work was supported under NAVSHIPS Subproject SF 11 121 300, Task 11198.

This material is being published to document the test results. Only limited distribution outside of NUC is intended.

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I. REASON FOR INVESTIGATION

The Amperex Corporation has had a special vacuum tube on the market for several years for use in industrial R-F induction heaters. Due to its special construction, the device is known as a "Field-Effect" tube and given the trade name of "Neotron". It has special characteristics which have attracted some attention by those in the field of high-powered audio amplifier development. These characteristics are:

A. Compactness

B. Large power gain

C. Ruggedness

D. Wide frequency response

E. High output power capabilities

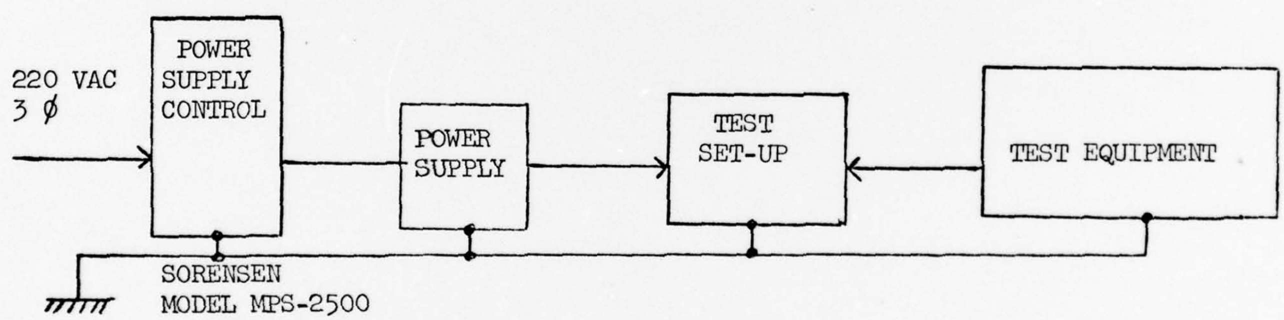
This report concerns itself with the investigation of the capabilities of the Neotron when used in high-powered sonar amplifiers which drive transducers in an array.

II. TEST SET-UP

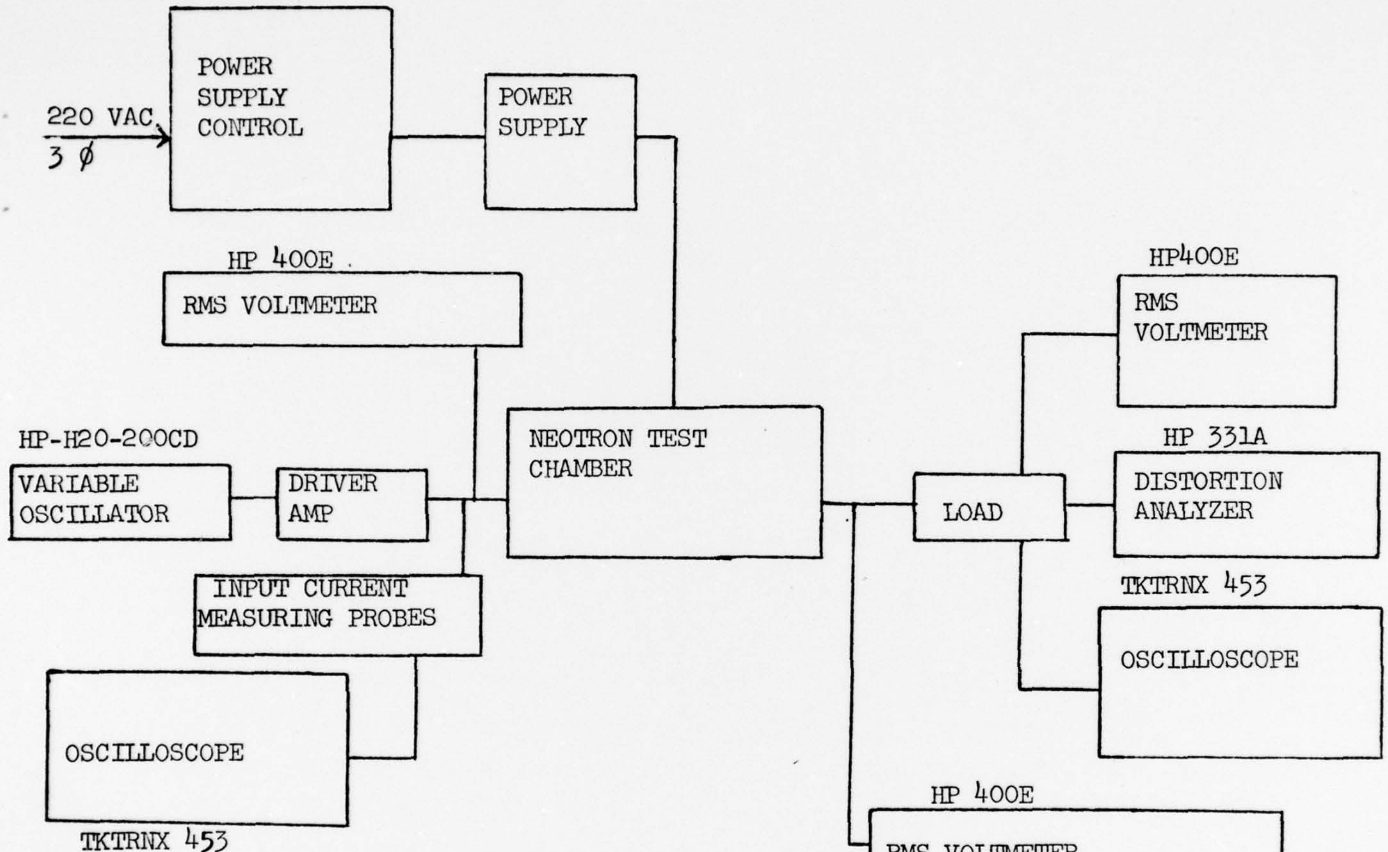
A 15K watt high voltage power supply was used to provide power for the test set-up. It had adjustable limits on the maximum voltage and the maximum current that it would provide. The absolute maximums were 6000 volts and 2.5 amperes. If the limits were exceeded, then the supply would shut itself down. It was then necessary to return all voltage controls to 0 volts before it could be reset. The voltage could then be increased to some level below the operating limits. When a limit was exceeded and the supply shut down, there were indicator lights that would indicate whether it was over voltage or over current

that had caused the shutdown. There were door interlocks to shutdown the power supply if a door was opened when the supply was operating. In the test set-up the door interlock circuit was also used in conjunction with a water flow switch in the cooling system to shutdown the power supply if the water flow was insufficient for proper cooling of the Neotrons.

The Neotrons were mounted in a plastic box one foot square and all sides were 1/2 inch thick. This was to protect personnel from contact with the high voltage during the evaluation. The power supply cabinets were connected together and bonded to an earth ground. Rubber matting was placed on the floor in front of the test bench and power supply cabinets for further personnel protection.



DETAIL OF TEST SET-UP



III. APPROACH

Four Neotrons with magnet nests were purchased.* Before these tubes arrived, the high voltage power supply and a filament and output transformers were acquired.

A test set-up was built to make the testing of these devices as accurate and as safe as possible.

The Neotrons were mounted inside a plastic box. They were connected to the output and filament transformers and also to the high voltage power supply and the water cooling system.

One Neotron was used for the class "A" tests and later two Neotrons were used for the class "B" tests. This left one as a spare.

IV. TEST PROCEDURES & RESULTS

A. Class "A" System (Diagram, page 19)

The first test set-up was made with a single Neotron operating in the class "A" mode of biasing. In the initial tests, a check of bias points versus the collector current was made and found to be nominal with the curves supplied by the manufacturer.

B. Tuned Class "B" (Diagram, page 19)

An output transformer was obtained from an existing power amplifier that could handle 4 KW on a short duty cycle. This was an output transformer tuned internally to 5.3 KHz. The Neotron was connected to this transformer and the high voltage and bias supplies were connected to this test set-up. Because the transformer was tuned, the bias point was brought down to -70 volts.

*$93.50 each including connectors and magnet nest.

By driving this test set-up, a power output into a resistive load of 4 KW as achieved. The efficiency was 75% at 4 KW including heater power and with 5000 volts collector supply. In this test, as well as the following tests, readings were taken with a sinusoidal wave that had less than 5% distortion.

C. Class "B" Push Pull (Diagram, page 20)

For this configuration, an untuned output transformer was used so that operation over more than a single frequency could be accomplished. This also allowed for voltage/current phase shift tests. The transformer had a tapped primary winding enabling the use of a Neotron on each half in a class "B" push-pull arrangement. The gate-to-gate driving transformer center tap was returned to system ground, thus setting the bias at 0 volts.

The maximum power output into a resistive load that was achieved in this set-up was 8.1 kilowatts.

To measure input drive power to the gates of the Neotron, an effort was made to measure the voltage and current on the primary of the input transformer. This was measured and noted, but it was found that the current and voltage were not in phase and that this phase changed with frequency. To bring the phase relationship back near 0°, the transformer was loaded with six, 100 KΩ resistors which made a combined load of 16.67 KΩ. With this load, the phase angle held around 7° through the band of frequencies from 1.5 KHz to 10 KHz. Now that the phase shift in the transformer was held constant in the primary of the input transformer, the next step was to add the gate load to the secondary of the transformer in addition to the resistive load. It was thought that the increased

current in the primary would be that which was the result of the additional load of the gates. It soon became apparent that the gate load was so small compared with the transformer loading resistors that it was impossible to measure any change of current due to gate loading.

The preceeding method was not capable of measuring the gate current. The next approach was an attempt to measure the voltage and current on the secondary side of the transformer which drives the gates. As this has a potential of around 1.5 KV peak to peak, it presents a measuring problem. A 1000 :: 1 high voltage attenuator probe was obtained and checked. The input transformer secondary was opened up and a 1 KΩ resistor was installed in each winding where they meet to form a center-tap. The high voltage probe was used to measure the voltage across the secondary of the transformer at three different voltage levels; namely 250V, 500V, 1000V RMS. At these three secondary voltages, the primary voltage was read and noted. This procedure made possible the measurement of the secondary voltage in terms of the primary voltage, since no current flowed in the secondary of the transformer due to the high voltage probe.

To measure the loss in the transformer, it was necessary to apply the drive voltage that would give the output across the secondary that was required for these tests. The current in each half of the secondary was measured by using an oscilloscope and high impedance probes across the 1 KΩ resistors. The voltage across each resistor was converted into current and tabulated for the three voltage levels and the frequencies of interest between 500 Hz and 10 KHz. By this method the current due to losses in the transformer was measured.

Since the Neotrons were operated in a class "B" mode, gate drive current only flowed during half of each cycle for each Neotron. To combine these half-cycle current waveforms they were applied to a two channel oscilloscope and the oscilloscope was operated in the "ADD" mode. This made a combined waveform that could be measured on the oscilloscope grid and then converted into current. The gate-to-gate impedance could be calculated from this information. It was difficult to make some of the low frequency, low level measurements. Because of this, there were three current readings taken at three different input drive levels for each frequency of interest. The gate-to-gate impedance for each of these drive levels was calculated and then these three impedances were averaged together to get a resultant gate-to-gate impedance for each frequency. There seemed to be some ambiguity between 500 Hz and 1 Kz. This likely was due to the fact the currents being measured were down in the 100 micro-ampere area. Some of this current measured was due to noise picked up while the Neotrons were being driven. The impedance was seen to become lower as frequency increased at approximately the same rate as a 100 $\mu\mu f$ capacitor would. From this, it appeared that the interelectrode capacity was around 100 $\mu\mu f$.

D. Output Transformer

The amplifier required that a transformer be designed to match the Neotrons to the existing 10Ω resistive water cooled load. The transformer was designed to handle up to 10 kilowatts of power for a 50% duty cycle. Taps on the primary and secondary were installed to allow a small change in the turns ratio to accommodate some loading changes.

E. Cooling

The cooling of the amplifier was accomplished by running city tap water through the cooling jackets of the Neotrons and then through the water jacket on the resistive load. Plastic tubing was used to carry the water to and from the amplifier. The water was in direct contact with the collectors on the Neotrons which were connected to the high voltage power supply. The leakage current due to the water path was 20 milliamperes at 5000 volts. A piece of plastic tubing was coiled to form a water path of 3.5 feet between the collectors, because a piece a few inches long would act as too much of a shunt from collector to collector. The volume of water flow to cool the Neotrons was 4.5 liters per minute. The temperature of the water entering the cooling jacket was 55°F and up to 125°F leaving the amplifier, depending on the amount of power being dissipated in the Neotrons.

F. Measurements

Power output tests were made at various input drive levels and into resistive and reactive loads. The maximum power achieved was 8.1 kilowatts into 10 Ω resistive load with a D.C. input power of 15 kilowatts. The efficiency at this power output is 54% including 60 watts of emitter heater power. Tests could not be run any higher because this was the limit of the high voltage power supply. During reactive load tests a single inductor or capacitor was installed in series with the 10 Ω load resistor and the frequency was changed to create voltage-current phase shift in the load while holding the input drive at some predetermined level. The phase shift during these tests ranged from $\pm 8°$ to $\pm 78.5°$. One interesting observation was made during

these runs; the power amplifier output remained in a constant power mode when operating into reactive loads. The voltage across the load remained constant while the volt-ampere output was changing. The amplifier was operating in the constant current mode. This was due to the fact that the turns ratio had to be adjusted to develop 285 volts across the fixed 10Ω load for 8.1 KW output.

During the course of this Neotron evaluation another item became apparent. The gate impedance is sensitive to collector supply voltage. When there is no collector supply voltage applied, the gate impedance is low in much the same manner as a transistor base to emitter junction is a low impedance with no collector supply voltage applied. However, the gate impedance appears to stabilize above 500 volts of collector supply voltage.

V. RESULTS

The Neotron appears to perform as well as the data sheets claim. In the class "A" configuration the voltage-current collector versus gate bias voltage curves were nominal with the published data.

The single ended tuned class "B" test set-up had an efficiency of 75%, but it could only operate at a single frequency. The maximum power out was 4 kilowatts.

The most extensive testing was done on the class "B" push-pull configuration. This was broad band, limited only by the input and output transformers. An output of 8.1 kilowatts was achieved using two Neotrons in a class "B" set-up with an efficiency of 54%. Each Neotron was dissipating about 3.5 kilowatts at this power output.

The devices will operate into $\pm 80°$ phase angle loads with no adverse effects. The curves showing the volt-amperes, power across the load resistor, and the phase angle between the voltage and current display a roll off of power and volt-amperes with a rapid increase in phase angle. This is due to operating below the lower cut-off of the transformer design. The point here is that this roll-off had nothing to do with the Neotron's operation. It was used to generate a large phase angle into which the Neotron had to operate. The limiting factor when operating at high phase angles and high drive voltages is the inverse breakdown voltage applied to the nonconducting Neotron during half of the cycle. If it is nonrecurring a single arc will develop and no damage will be suffered by the Neotron. If it is allowed to continue arcing, internal heat can cause gas to be formed from the metal parts.

During set-up for a frequency response test, an RF arc developed between the plastic tubings connecting the collectors with the cooling water. The arc melted the plastic tubing, thus allowing the water under pressure to be sprayed around the inside of the plexiglass box containing the two Neotrons and the driver transformer. The water formed a conductive path between the positive and negative terminals of the 6000 volt supply. The power supply has over current limiting and this acted to shutdown the power supply. After the water was cleaned out of the box and the plastic tubings were replaced, the power was applied again. The Neotron amplifier performed in a normal manner indicating that no damage had been sustained.

On another occasion an arc developed between the plastic tubing connected to one of the collectors and a gate connector. Water

again sprayed the inside of the box and shutdown the power supply. After repairs were made, as in the previous instance the amplifier performed in a normal manner.

These two incidents are mentioned to demonstrate that the Neotrons can survive momentary short circuits involving the high voltage on the collector and the input signal on the gate. Also there were times when the amplifier was driven with full input drive voltage and the load was disconnected. This caused no adverse effects on the Neotrons.

VI. CONCLUSIONS

The tests described in this report have shown the Neotron to be rugged, have high power capabilities, and have high power gain; some of the attributes required of power conversion devices when used in sonar power amplifiers.

VII. RECOMMENDATIONS

The tests performed during this program have suggested that further evaluation is needed to fully exploit the devices' capabilities. It is therefore recommended that:

A. Tests be run at higher power levels with short pulses and appropriate duty cycles to keep within the devices ratings.

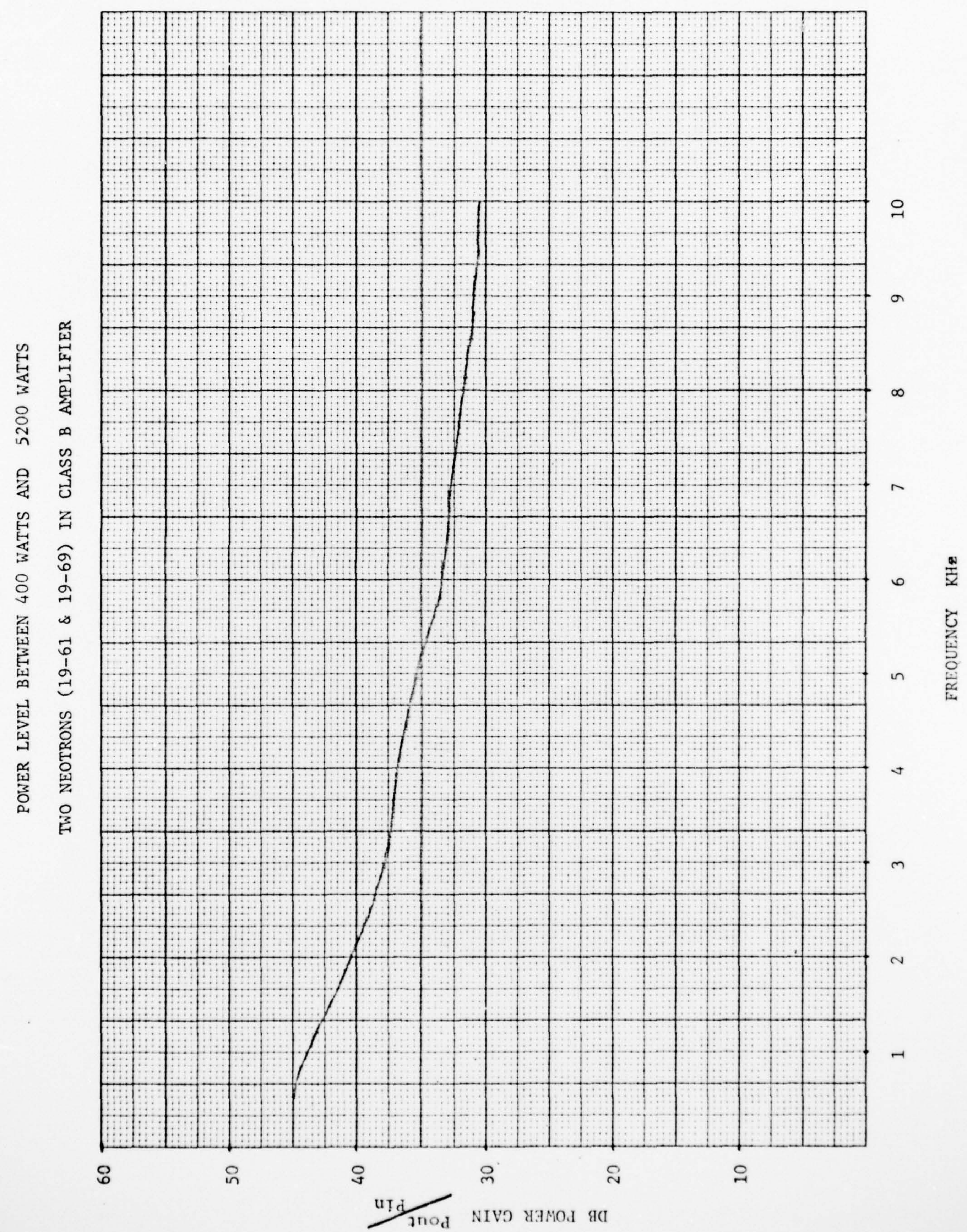
B. The reliability of the Neotron be determined to some extent by running extended life tests in a high power pulse mode.

C. An amplifier similar to the class "B" be operated over the 1 to 5 KHz range with a wide range of resistive and reactive loads to

determine the amplifier's tolerance to such loads.

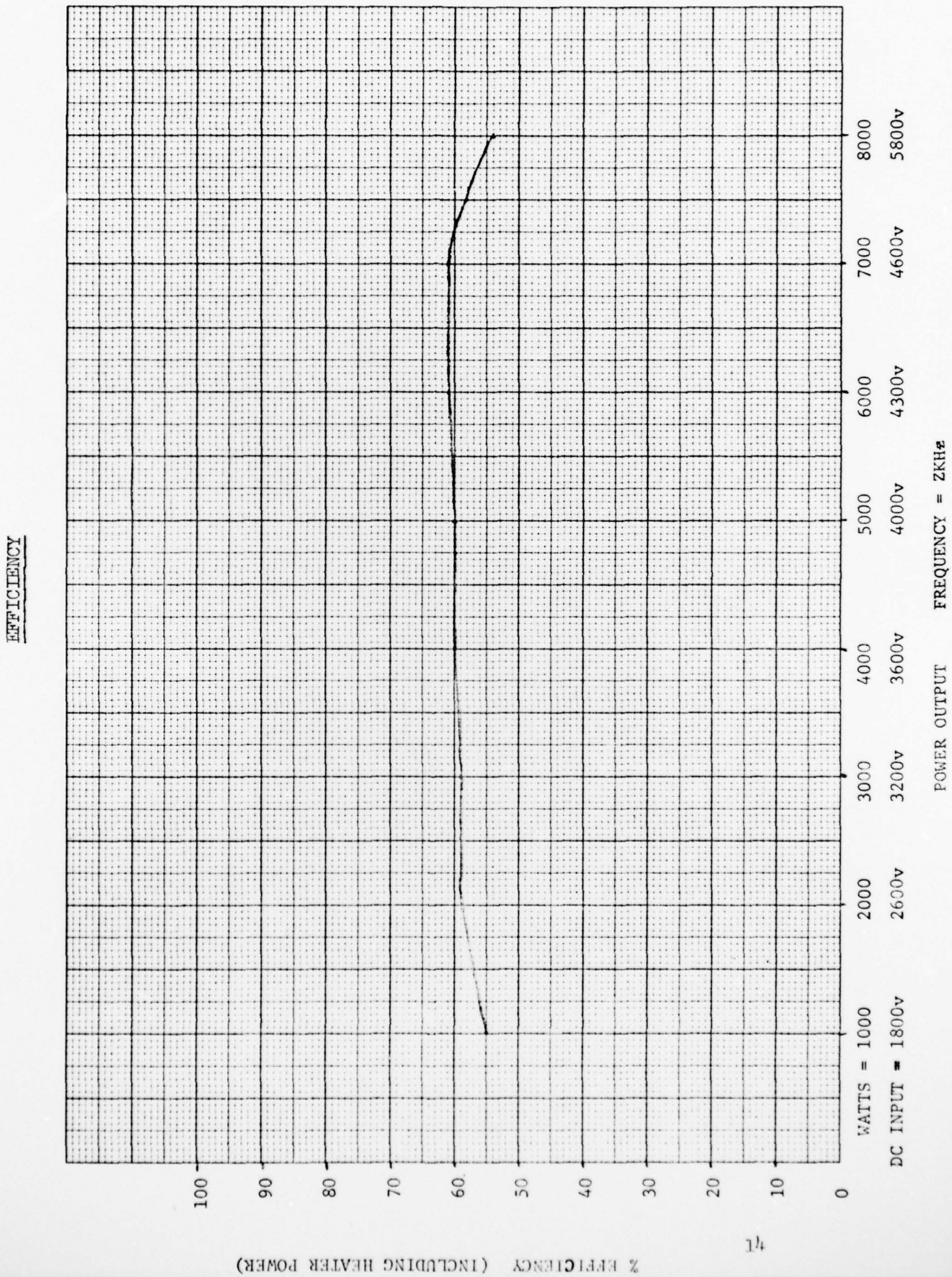
D. An amplifier (or amplifiers) be designed and built to work with available transducers and operated (singly or in an array) in the water.

POWER GAIN VS FREQUENCY

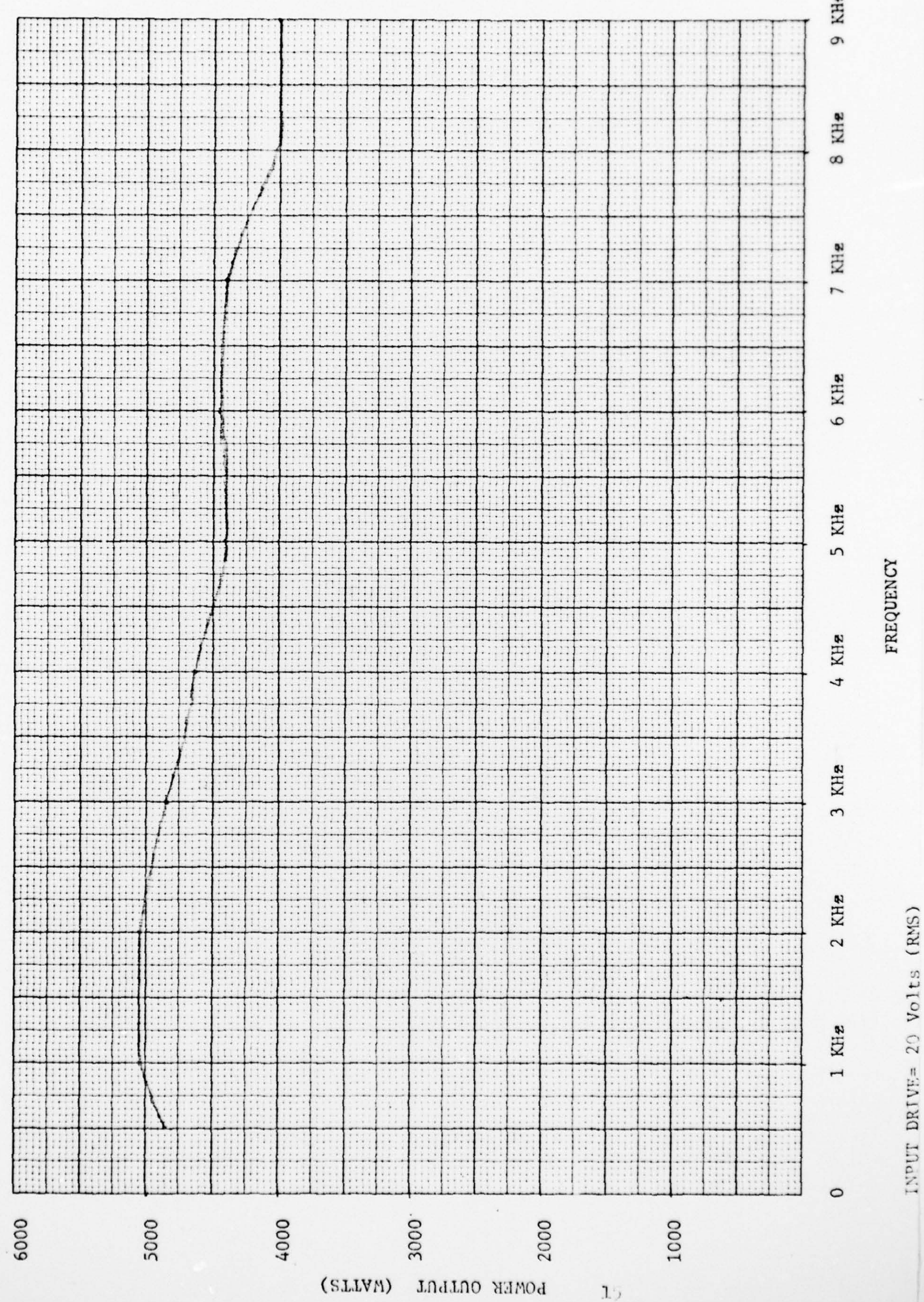


NEOTRON PAIR (F-527 & 19-69) IN CLASS "B" AMPLIFIER

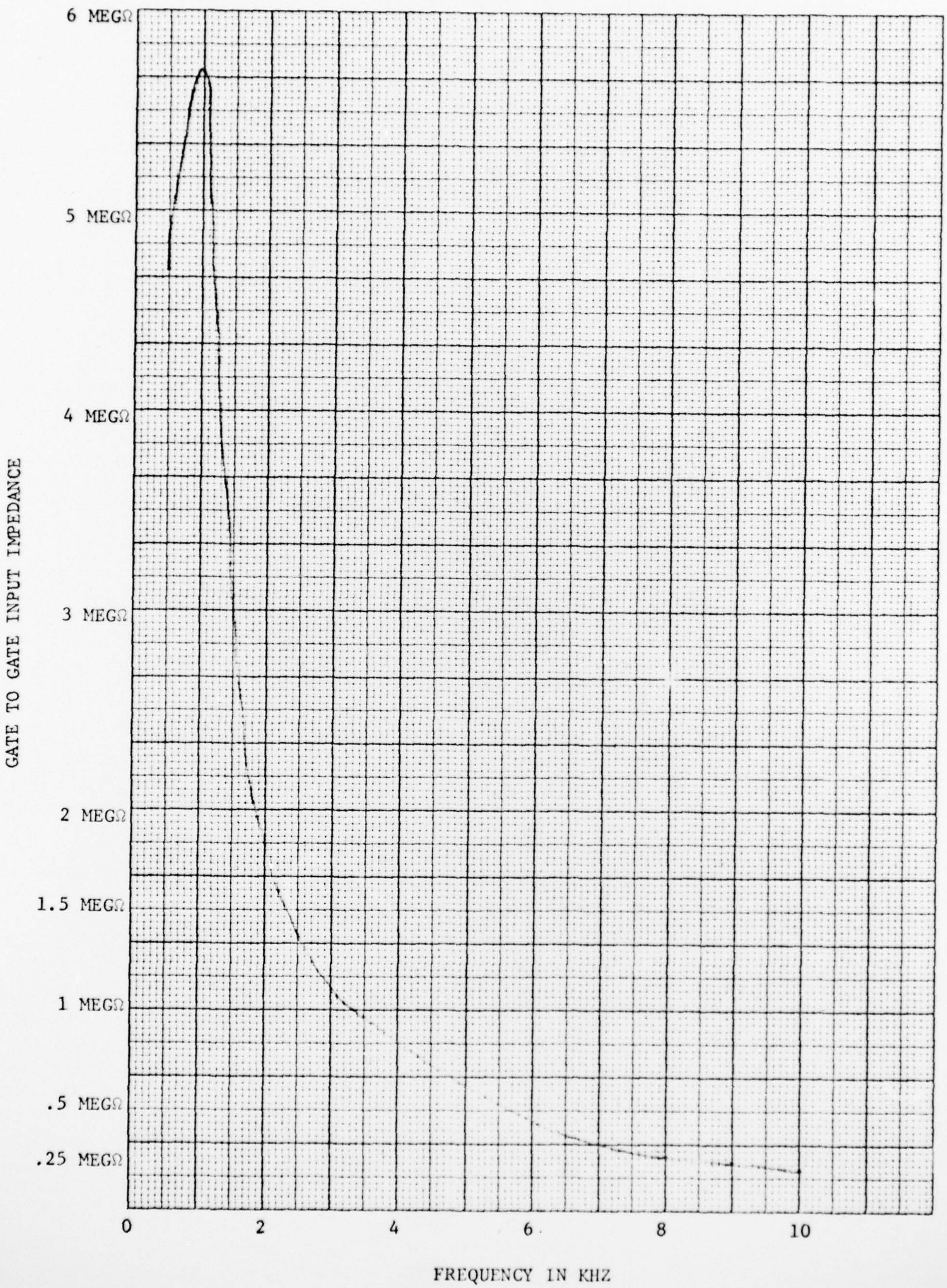
MAXIMUM DISTORTION IS 5%

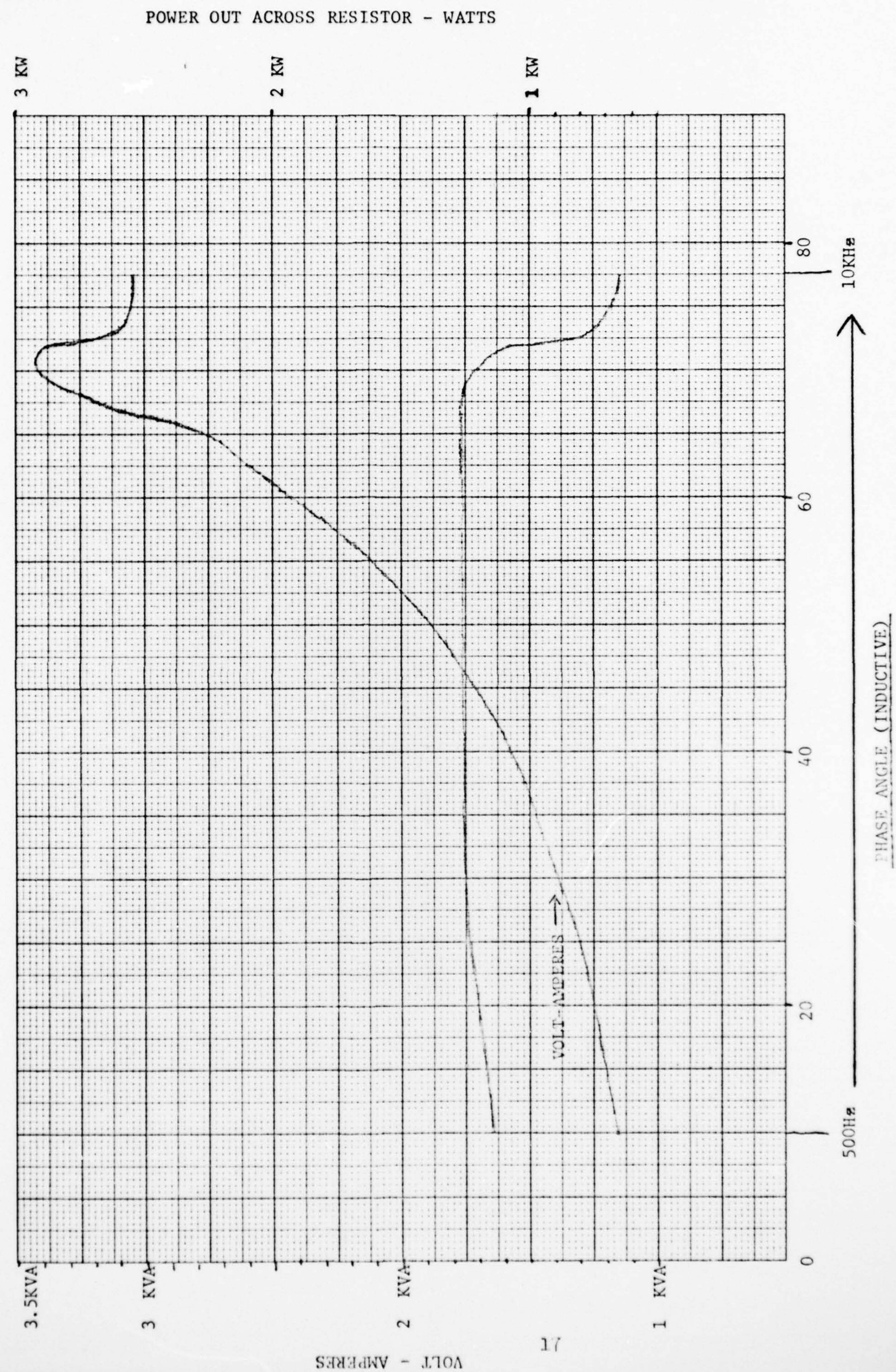


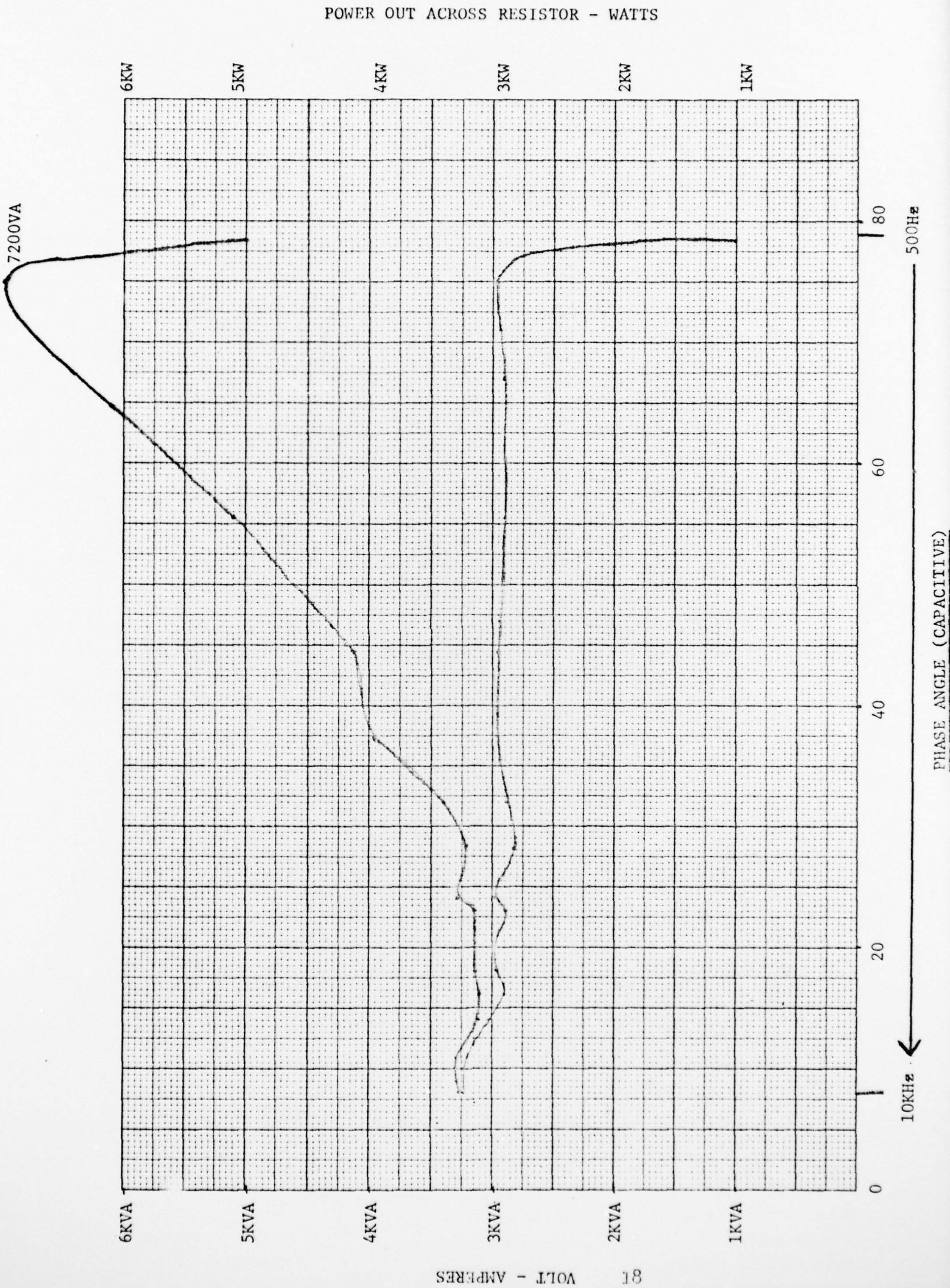
POWER OUTPUT VS FREQUENCY

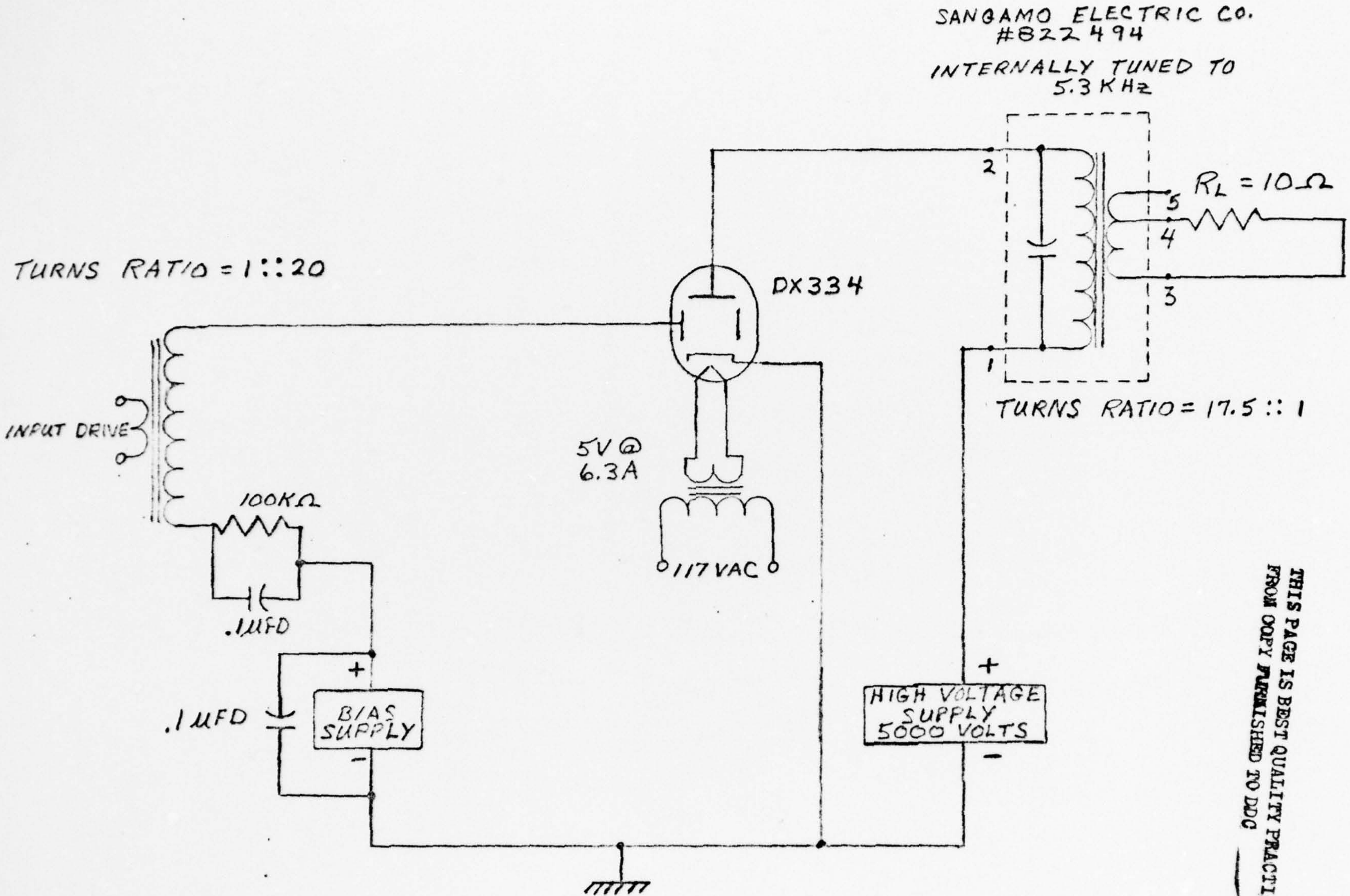


<u>INPUT IMPEDANCE</u>

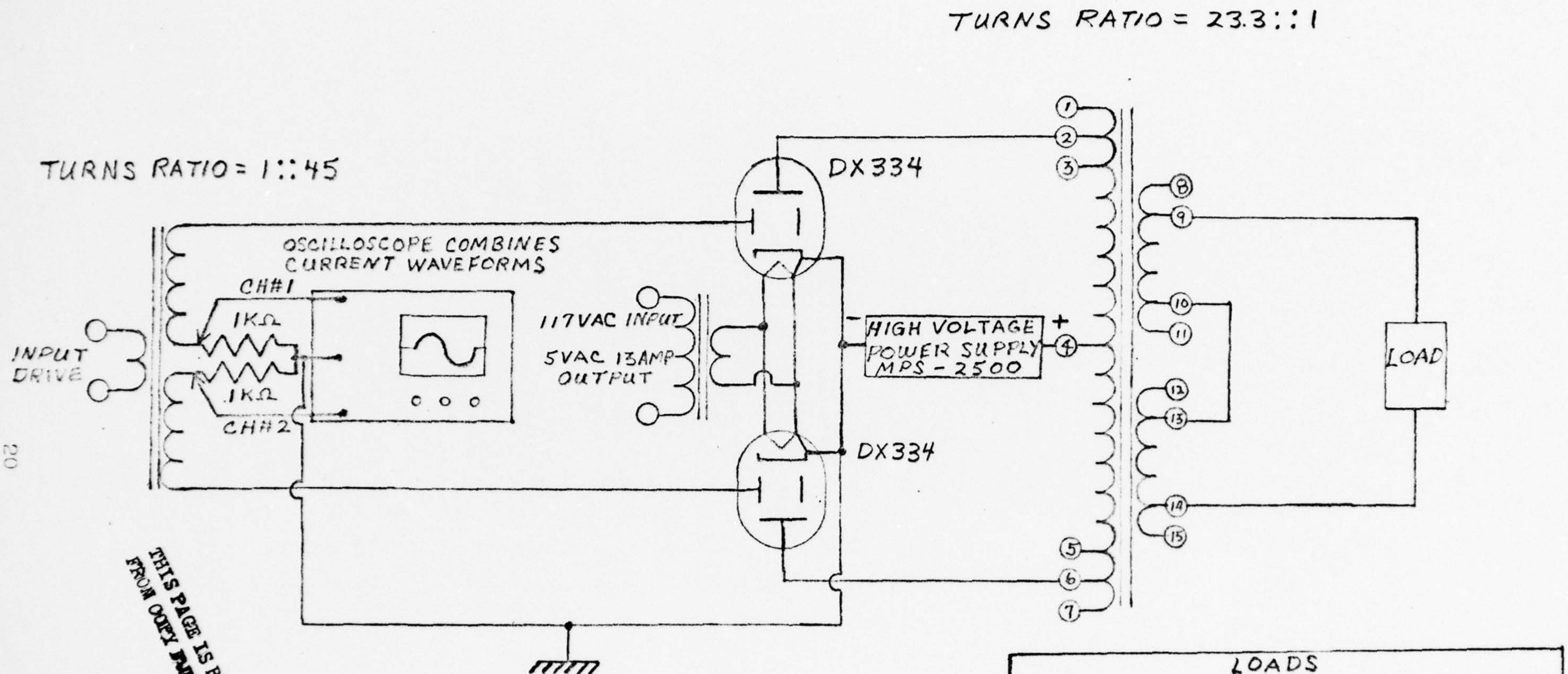



POWER OUT ACROSS RESISTOR - WATTS
3 KW
2 KW
1 KW
3.5KVA
3 KVA
2 KVA
1 KVA
VOLT - AMPERES
VOLT-AMPERES
0
20
40
60
80
500Hz
10KHz
PHASE ANGLE (INDUCTIVE)


POWER OUT ACROSS RESISTOR - WATTS
6KW
5KW
4KW
3KW
2KW
1KW
7200VA
80
500Hz
60
40
20
0
10KHz
PHASE ANGLE (CAPACITIVE)
6KVA
5KVA
4KVA
3KVA
2KVA
1KVA
VOLT - AMPERES

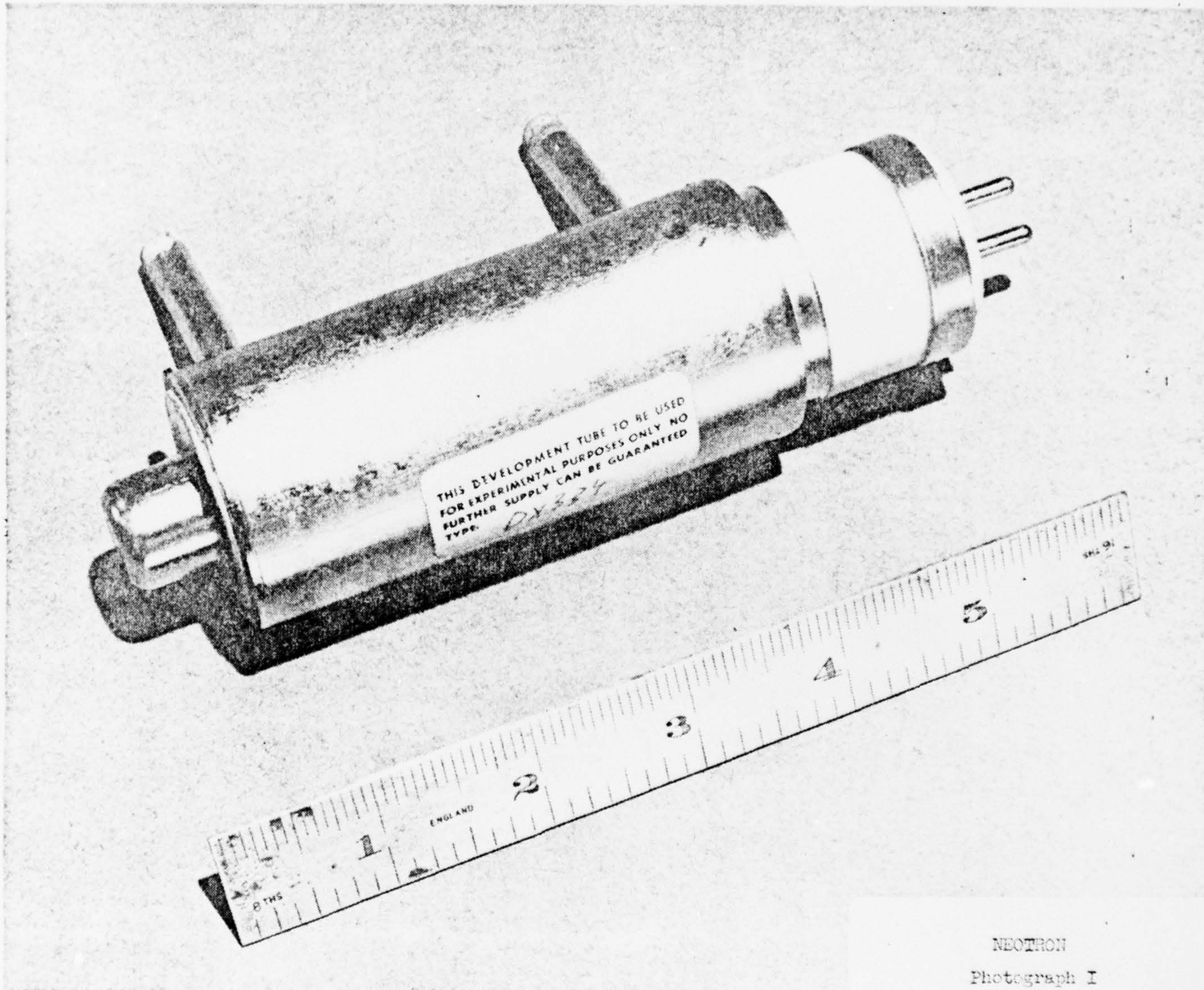


CLASS A & CLASS B SINGLE ENDED (TUNED)



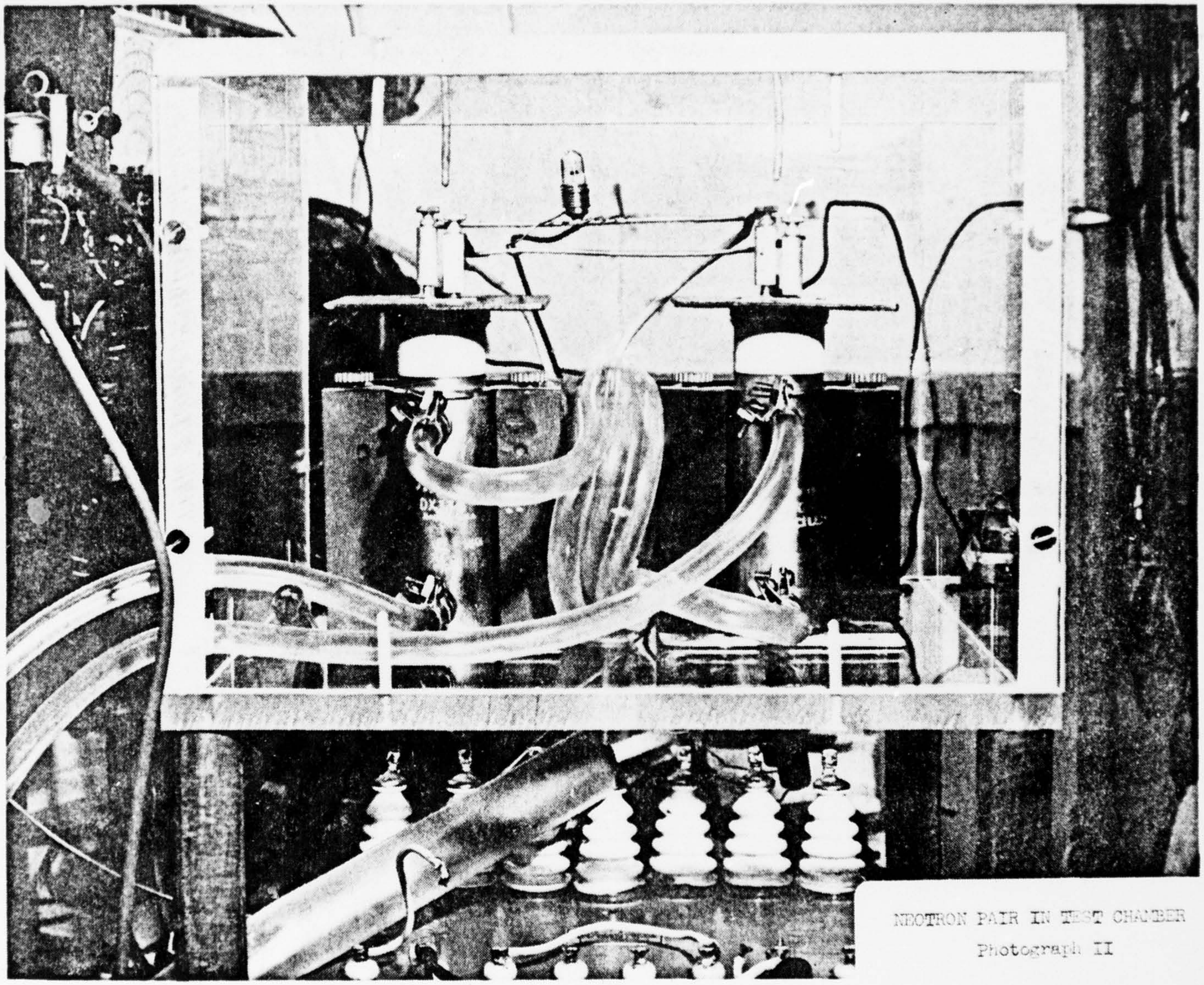
LOADS		
R	CR	LR
10Ω RESISTOR	8 MFD CAPA. IN SERIES WITH 10Ω RESISTOR	0.64 MH IND. IN SERIES WITH 10Ω RESISTOR

CLASS B BROADBAND



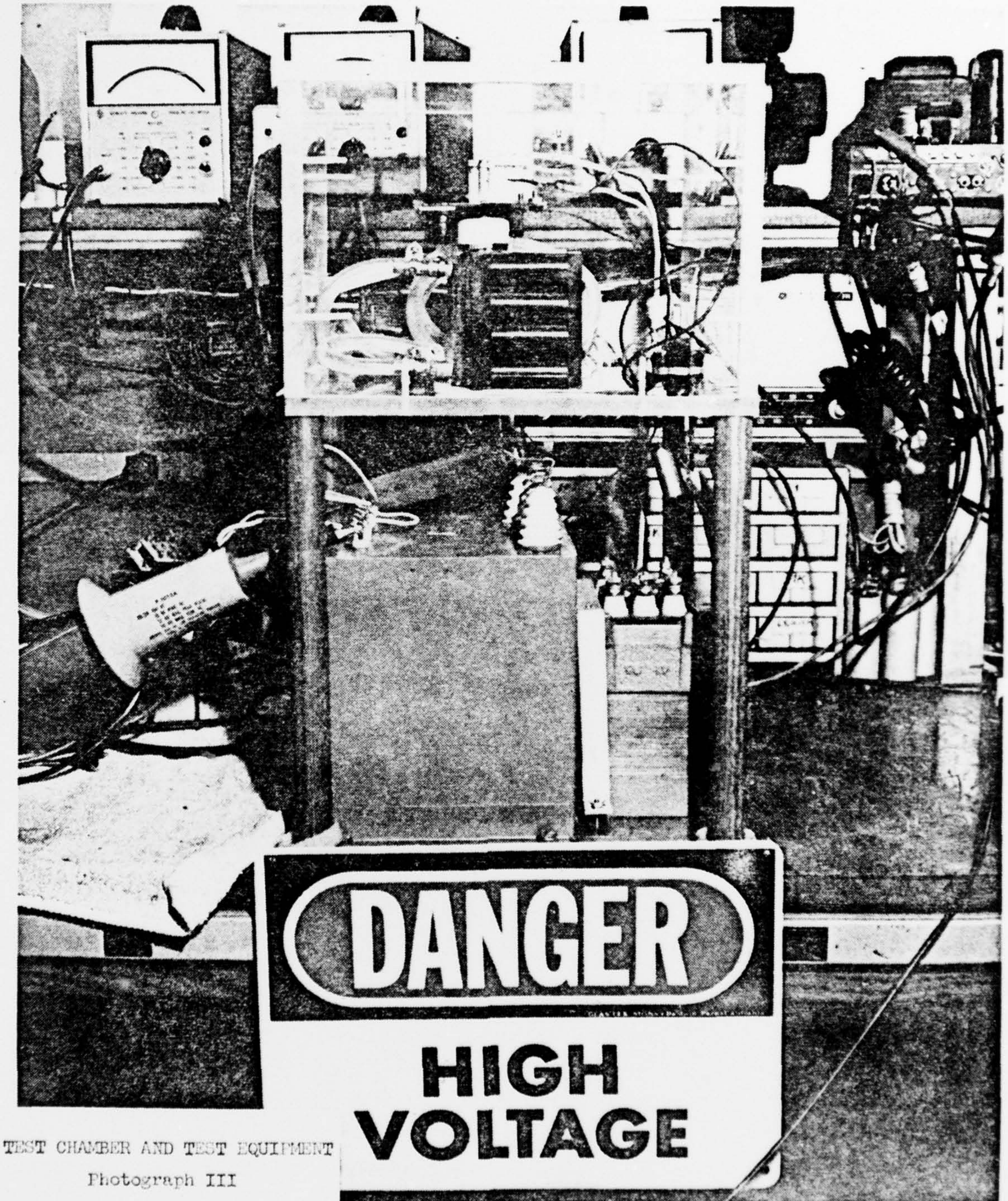
NEOTRON

Photograph I



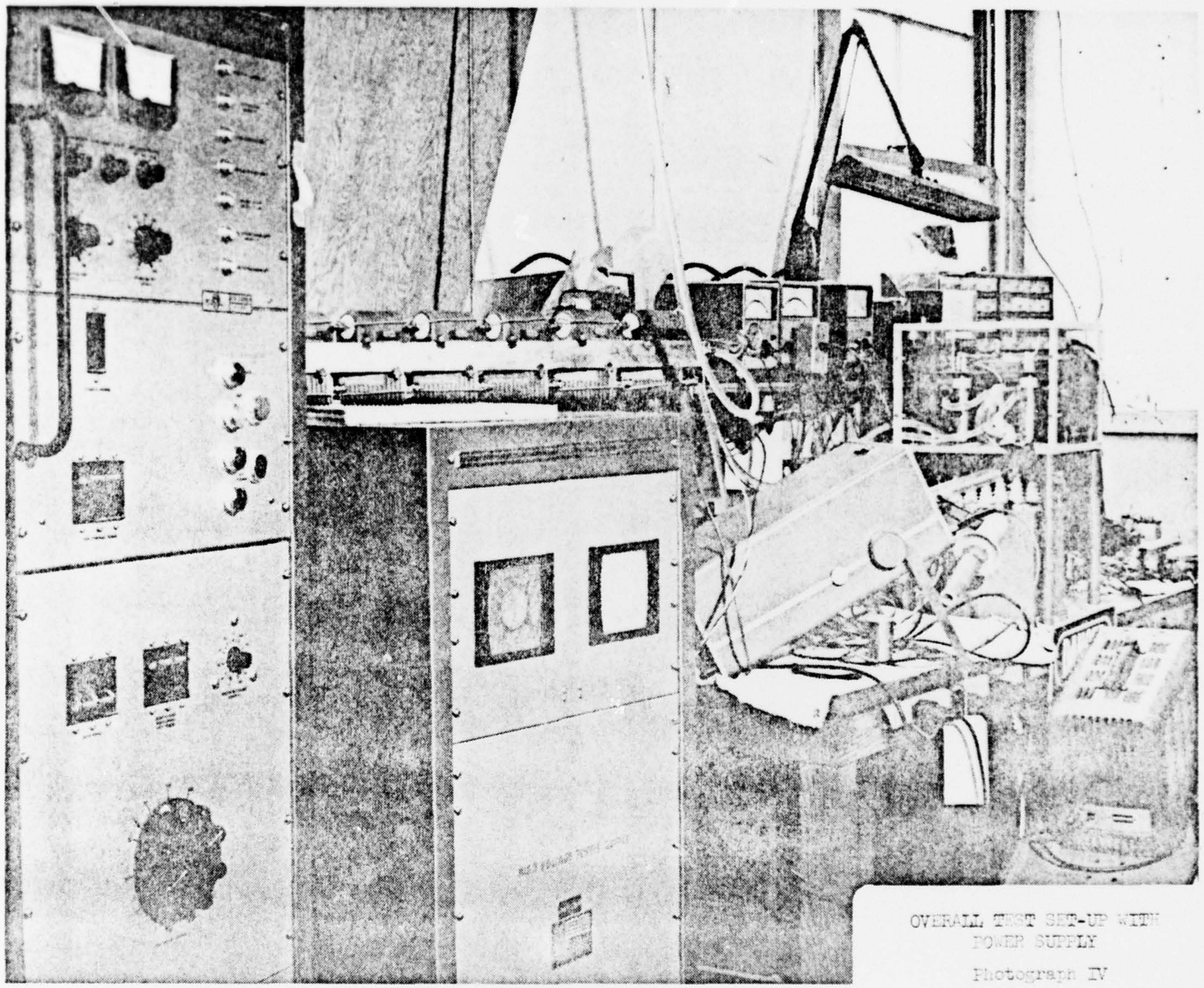
NEOTRON PAIR IN TEST CHAMBER

Photograph II



TEST CHAMBER AND TEST EQUIPMENT

Photograph III



OVERALL TEST SET-UP WITH
POWER SUPPLY

Photograph IV